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A Compact Meandered CPW-Fed Antenna with Asymmetrical Ground Plane for 5.8 GHz RFID Applications with Multiple Split Ring Resonator

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Abstract—In this paper, a Multiple Split Ring Resonator (MSRR) based coplanar waveguide (CPW) fed antenna for 5.8 GHz RFID application is presented. The antenna has a compact size of $15 \times 21 \times 0.8\,\mathrm{mm}^3$. The proposed antenna is designed, fabricated and tested. The simulated results are discussed and in good compliance with the measured results. Split Ring Resonator (SRR) characteristics are also studied. The proposed antenna shows good performance at the measured resonance frequency of 5.75 GHz.

1. INTRODUCTION

Metamaterial inspired antennas were investigated for the design of compact antennas [1–4]. Metamaterials are artificial homogeneous structure synthesized to display simultaneously negative permeability and negative permittivity. SRR is one of the key elements of metamaterial. SRR is used to provide negative permeability characteristics. SRR is μ-negative metamaterial. SRR and CSRR are two basic structures of artificial metamaterial [5, 6]. There are many different SRR structures reported in the literature such as Multiple Split Ring Resonator (MSRR), Labyrinth Resonator (LR), Spiral Resonator (SR), Broad Side Coupled Split Ring Resonator (BCSRR), and Non-Bianisotropic Split Ring Resonator (NBSRR) [7, 8]. SRR is an electrically tiny, homogeneous and resonant structure designed to display negative permeability. In general, SRR can be used as notch element for UWB antenna and can also be used for bandwidth improvement. Negative permeability (stopband) frequency range is used for notch function [9], and positive permeability (pass band) is used for bandwidth improvement [2]. Due to the resonant nature of SRR, it was explored for the design of compact radiating element for CPW-fed antennas and microstrip planar antennas. SRR structures such as triangular split ring resonator [10], circular split ring resonator [11] and hexagonal split ring resonator [12] were used as radiating elements for CPW-fed antennas instead of large size radiating element. Due to the tiny size of SRR, obtaining good impedance matching is difficult. Some desired changes have been done in order to obtain good impedance matching either in ground plane or CPW feed. SRR based antenna with trapezoidal ground plane and CPW tapered feed line was designed for dual-band antenna. Meandered CPW-fed antenna with hexagonal shape SRR was designed. Meandered feed was used to attain good impedance matching but Hex-SRR characteristics were not studied.

The objective of this paper is to study the performance of a meandered CPW-fed circular shape SRR with multiple-split based antenna. Meandered CPW feed with asymmetrical ground is utilized for good impedance matching. Meandered feed line is used to obtain good impedance matching. In general, meandered line technique is employed to increase the resonant length of the antenna without physically changing the size instead of simple CPW. SRR's stopband and passband characteristics are studied for

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good understanding. Multiple-split SRR is used to get desired frequency band. The proposed antenna is designed, simulated and optimized by using electromagnetic simulator software HFSS.

2. ANTENNA DESIGN AND SIMULATED RESULTS

The antenna evolution stages are shown in Figure 1. The meandered CPW-fed conventional SRR based monopole antenna is studied in the first step. The simulated return loss characteristics of evolution stages are shown in Figure 2. The resonance frequency of 5.44 GHz with return loss of −26 dB is observed for the first step. In order to further improve the return loss, an antenna with asymmetrical ground plane is analyzed. In the second step, studies are carried out for wider left-side asymmetrical ground

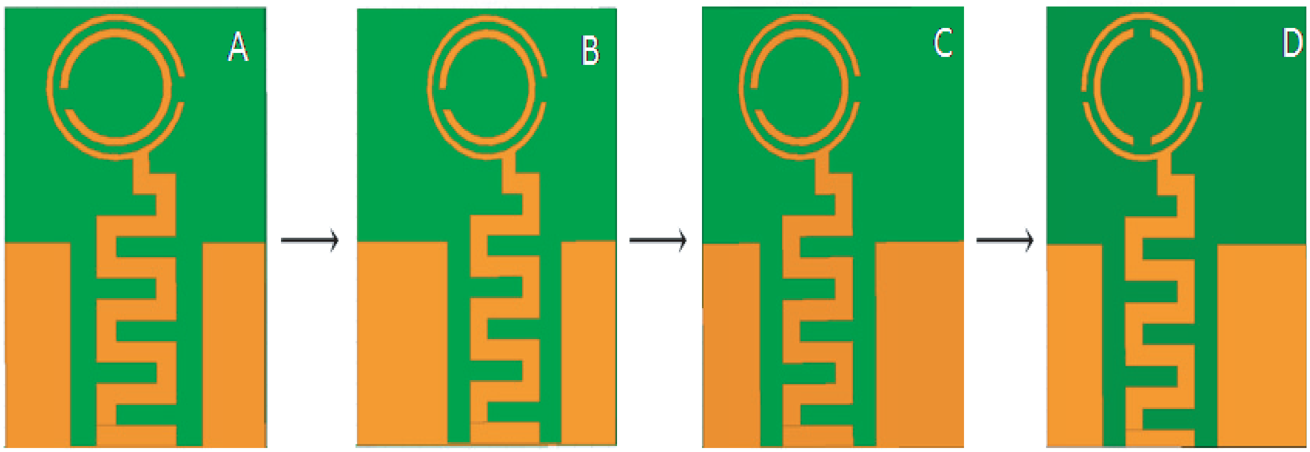

Figure 1. Evolution stages of proposed antenna.

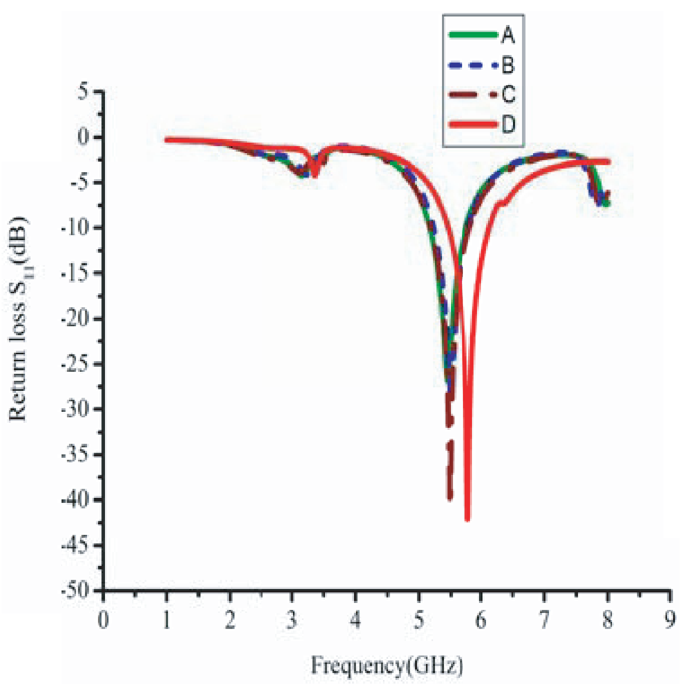

Figure 2. Simulated return loss S_{11} (dB) of antenna evolution stages.

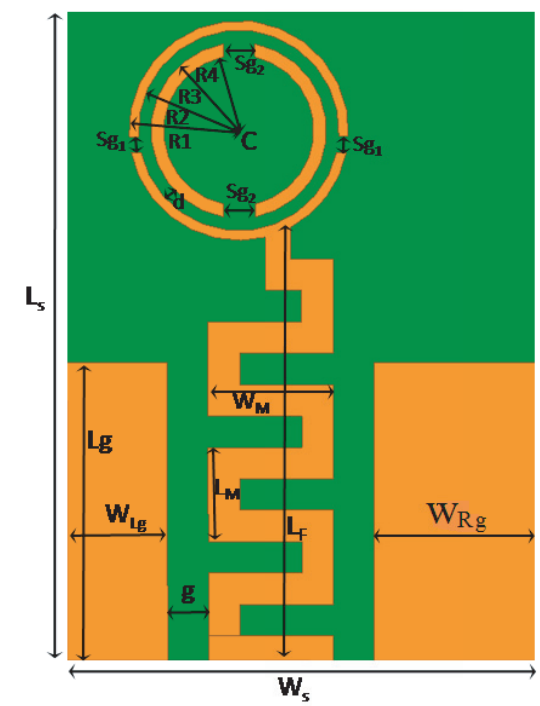

Figure 3. Antenna geometry.

plane ($W_{Lg} = 5.2$ mm, $W_{Rg} = 3.2$ mm). Antenna with wider left ground plane generates resonance frequency of 5.49 GHz with a return loss of −28 dB. In the third step, a CPW-fed antenna with wider right ground plane ($W_{Lg} = 3.2$ mm, $W_{Rg} = 5.2$ mm) is studied, which produces resonance frequency of 5.48 GHz with a return loss of −40 dB. The wider right ground plane produces good return loss than wider left ground plane. Hence, wider right ground plane is finalised for the proposed design. In the fourth step, a conventional SRR with two splits is replaced by an SRR with multiple splits in order to get desired resonance frequency and frequency of RFID applications. For SRR, as the number of splits is increased, capacitance decreases which in turn increases the resonance frequency. Hence, resonance frequency is shifted to 5.8 GHz from 5.48 GHz with good return loss of −42 dB. SRR with four splits is finalised for the proposed antenna. The comparison of performance of evolution stages is given in Table 1. The proposed antenna has meandered CPW feed, SRR with four splits and asymmetrical ground plane. The antenna geometry is shown in Figure 3.

The proposed antenna is fabricated on a low cost FR4 substrate with dielectric constant 4.4 and thickness 0.8 mm. The antenna is fed by meandered CPW feed line. The radiating element consists of SRR with four splits. The width of the outer split ring is 0.3 mm, and width of the inner split ring is 0.4 mm. The distance between inner and outer split rings is 0.4 mm.

Table 1. Comparison of antenna evolution stages.

Evolution Stages	Frequency range (GHz)	Bandwidth (GHz)	Resonant frequency (GHz)	S_{11} dB at f_r (dB)
A	5.16–5.74	0.58	5.44	−26.74
B	5.22–5.781	0.561	5.494	−28.53
C	5.2–5.802	0.602	5.48	−40.29
D	5.459–6.103	0.644	5.78	−42 dB

The antenna dimensions are as follows: $Ls = 21$ mm, $Ws = 15$ mm, $W_{Lg} = 3.2$ mm, $W_{Rg} = 5.2$ mm, $Lg = 9.8$ mm, $W_M = 4$ mm, $L_M = 3$ mm, $R_1 = 3.5$ mm, $R_2 = 3.2$ mm, $R_3 = 2.8$ mm, $R_4 = 2.4$ mm, $Sg_1 = 0.5$ mm, $Sg_2 = 1$ mm, C (19 mm, 17.2 mm, 0.8 mm), $d = 0.4$ mm, $L_F = 14.1$ mm, $g = 1.3$ mm.

3. PARAMETERS EXTRACTION OF MULTIPLE SPLIT RING RESONATOR

The MSRR structure and its equivalent circuit are shown in Figures 4 and 5, respectively. The proposed MSRR consists of two concentric metallic rings and four splits. The inductance of MSRR is due to

Figure 4. Proposed MSRR structure.

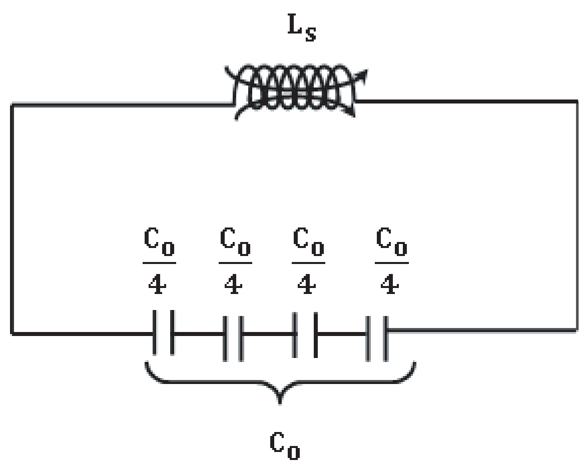

Figure 5. Equivalent circuit of proposed MSRR structure.

metallic rings, and capacitance is due to slots between the metal rings and four split gaps. The waveguide setup shown in Figure 6 is used to extract the S parameters S_{11} and S_{21} of MSRR. The simulated transmission and reflection coefficients of MSRR are shown in Figure 7. The permeability characteristics of MSRR are shown in Figure 8. The negative permeability and resonance frequency of MSRR are observed from transmission coefficient of MSRR. The resonance frequency of MSRR is 5.3 GHz, and the negative permeability is observed for the frequency range 5.2–5.4 GHz. The permeability of MSRR is positive over the desired frequency range. Passband is observed above the frequency 5.4 GHz. MSRR

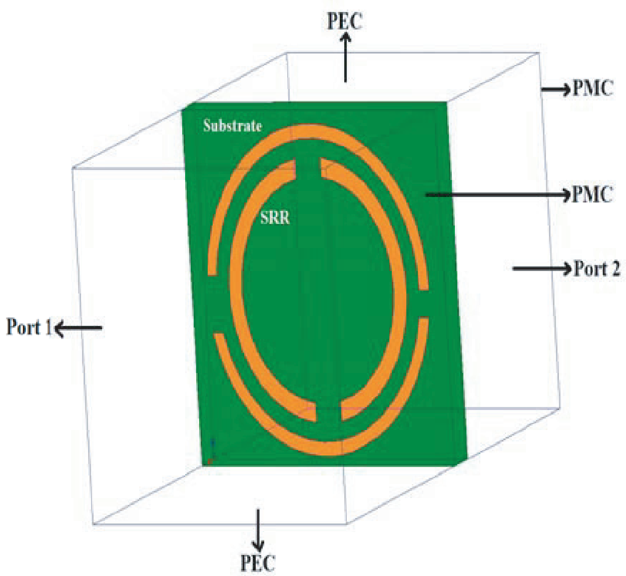

Figure 6. Waveguide setup to extract MSRR characteristics.

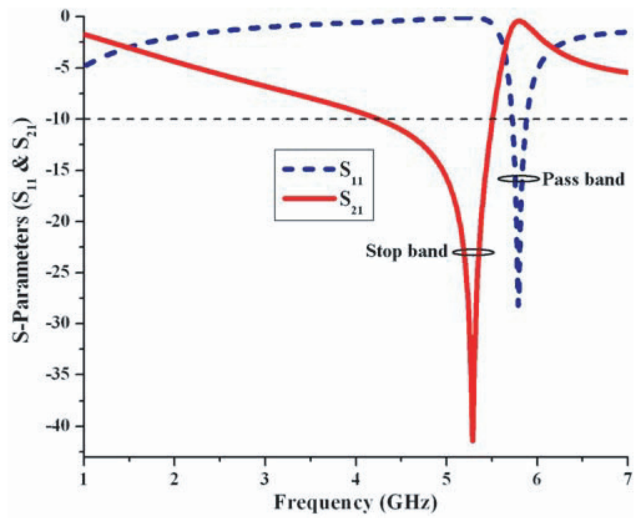

Figure 7. S_{11}(dB) and S_{21}(dB) of proposed MSRR.

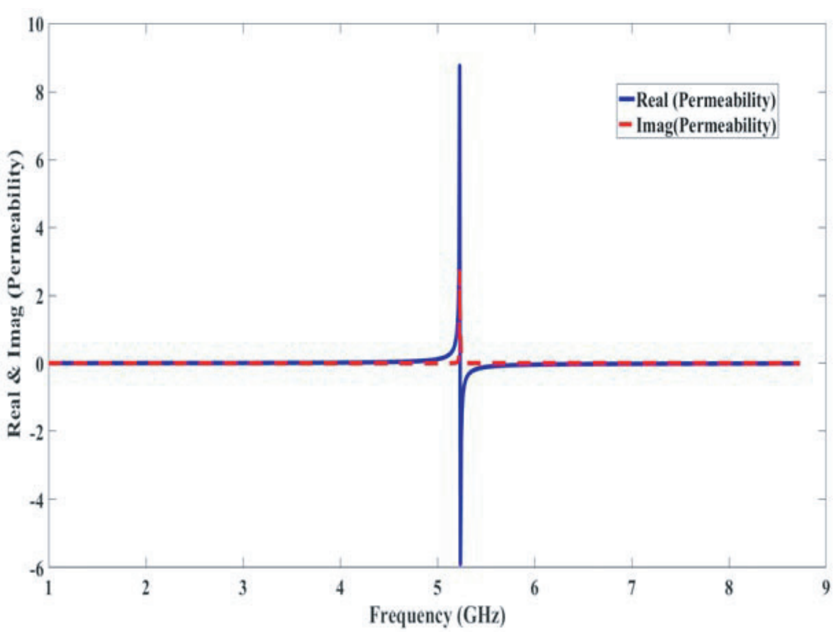

Figure 8. Permeability characteristics of MSRR.

Figure 9. Photograph of the fabricated antenna.

offers negative permeability characteristics due to stopband behaviour (S_{21}), and passband behaviour (S_{11}) creates a resonance frequency of 5.8 GHz for RFID applications. Hence, it is validated that the proposed MSRR can be used as a radiating element, and the passband characteristics of MSRR lie in the antenna's desired band. The stopband frequency range of MSRR lies below the antenna's desired frequency band. The resonance frequency of MSRR can be calculated by the following expression [13].

$$f_{SRR} = \frac{c}{2\pi^2}\sqrt{\frac{3(r_1 - r_2 - w)}{Re(\varepsilon_r) r_1^3}} \tag{1}$$

r_1 — radius of the outer ring, r_2 — radius of the inner ring, w — width of the metal ring, ε_r — dielectric constant.

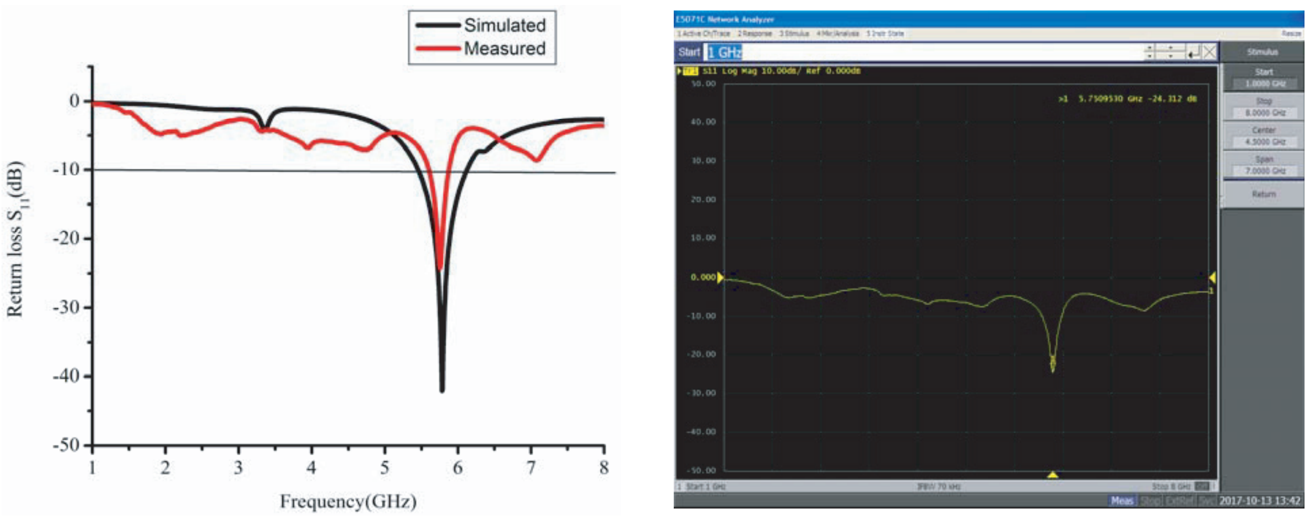

Figure 10. Simulated and measured return loss S_{11} (dB) of the proposed antenna.

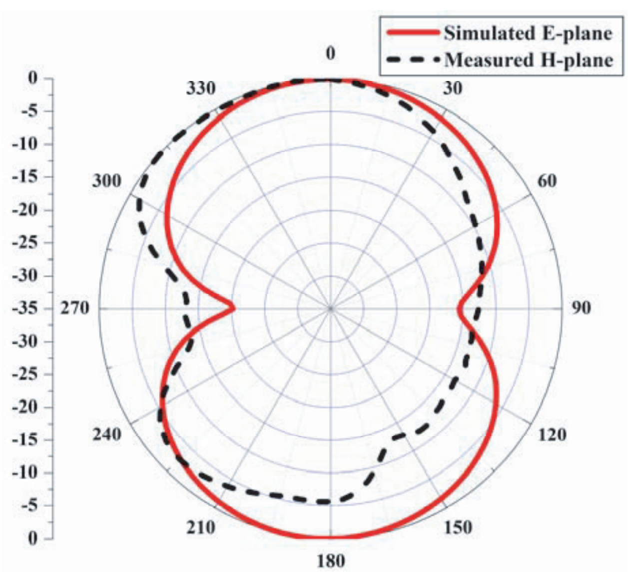

Figure 11. Simulated and measured radiation pattern in E-plane at 5.77 GHz.

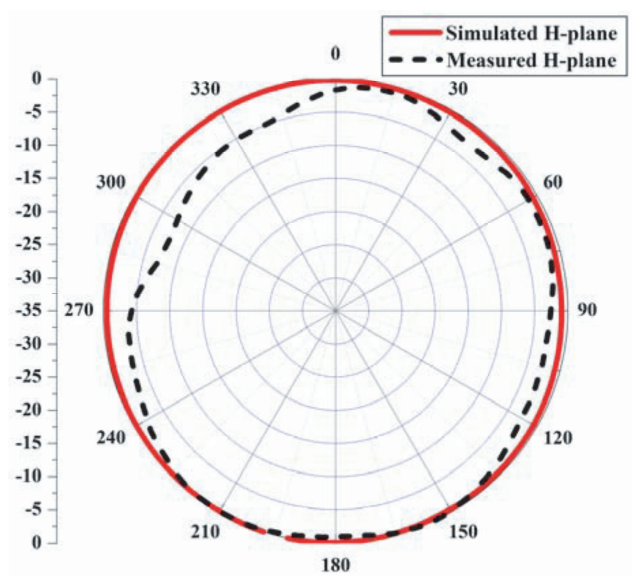

Figure 12. Simulated and measured radiation pattern in H-plane at 5.77 GHz.

4. RESULTS AND DISCUSSION

A photograph of the fabricated antenna is shown in Figure 9. The simulated and measured return losses of the antenna are depicted in Figure 10. The measured results show that the antenna has the frequency range of 5.61–5.88 GHz with resonant frequency of 5.77 GHz. The return loss at the measured resonant frequency is −24.15 dB. The comparison of measured and simulated results is given in Table 2. The far-field radiation patterns in E-plane and H-plane of the antenna at 5.77 GHz are shown in Figures 11 and 12. Radiation pattern plots show bidirectional pattern in E-plane and omnidirectional pattern in H-plane. The simulated gain and radiation efficiency at the resonant frequency are 3.4 dB and 97%.

Table 2. Comparison of simulated and measured results.

	Frequency range (GHz)	Bandwidth (GHz)	Resonance frequency (GHz)	Return loss at Resonance frequency (dB)
Simulated	5.459–6.103	0.644	5.8	−42
Measured	5.61–5.88	0.27	5.77	−24.15

5. CONCLUSION

A compact meandered CPW-fed antenna is designed using MSRR as radiating element. The size of the radiating element is very small. The combination of meandered feed and MSRR based radiating element could be used to achieve good impedance matching. SRR characteristics are highlighted to validate the results. The proposed antenna with compact size and good radiation characteristics could be useful for RFID applications.

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